REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	01/11/2006	Technical Report, June 2002 to Present

4. TITLE AND SUBTITLE
Maintaining endurance performance at high altitude (4300 m) despite severe energy intake deficit

5. FUNDING NUMBERS

6. AUTHOR(S)
Charles S. Fulco, Stephen R. Muza, Anne L. Friedlander, Paul B. Rock, Barry Braun, Carol J. Baker-Fulco, and Allen Cymerman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Thermal and Mountain Medicine Division
U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

8. PERFORMING ORGANIZATION REPORT NUMBER
T07-01

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Same as #7 above

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Body weight (BW) and lean body mass (LBM) of sea-level (SL) residents are typically reduced by < 4% and < 2%, respectively, while endurance performance is greatly impaired initially but then improves during the first three weeks of altitude exposure. The purpose of this study was to determine if a greater reduction in LBM due to severe energy intake deficit will eliminate the performance improvement despite maintenance of a high carbohydrate (CHO) diet. Two groups of men (mean ± SE: 22 ± 1 yrs) were matched at SL on cycle peak oxygen uptake (VO2peak), cycle endurance performance (50% of VO2peak for 50 min followed by 70% of VO2peak to exhaustion), total energy intake, and percent of energy from CHO (%CHO). At ALT, the deficit group (DEF, n = 10) consumed 1340 kcal/day (-40%) below BW maintenance requirements and the adequately fed group (ADQ, n = 7) ingested enough energy to maintain BW. Both groups ingested similar %CHO (~64 to 71%) and >347 g of CHO/day at SL and ALT. Endurance performance was again assessed at ALT on days 1 and 18 using the identical absolute power outputs that were used at SL for 50% (149 ± 4 watts) and 70% (218 ± 6 watts) VO2peak. From SL to day 18 at ALT, BW was reduced for DEF (80.4 ± 12 to 74.3 ± 3 kg; -8 ± 2%; P<0.01) but not ADQ (74.4 ± 3 to 73.3 ± 3 kg; -1 ± 1%). Similarly, LBM was reduced for DEF (71.0 ± 10 to 66.4 ± 7 kg, -6 ± 1%; P<0.01) but not ADQ (66.3 ± 5 to 64.9 ± 5 kg; -2 ± 1%). On either day at ALT, there was no difference between groups in endurance time. For both groups, endurance performance at ALT was 6 ± 2% greater on day 18 (57 ± 2 min) than on day 1 (54 ± 1 min; P<0.012). It was concluded that during the first three weeks of ALT acclimatization, a 6% loss in LBM due to underfeeding did not adversely affect the improvement in endurance performance. The lack of effect on performance during severe energy deficit may have been due to the maintenance of muscle glycogen stores or a lower rate of muscle glycogen utilization for the same amount of work.

14. SUBJECT TERMS
Weight loss, altitude, performance, strength, endurance, glycogen

15. NUMBER OF PAGES
20

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited Distribution

USARIEM TECHNICAL REPORT T07-01

MAINTAINING ENDURANCE PERFORMANCE AT HIGH ALTITUDE (4300 M) DESPITE SEVERE ENERGY INTAKE DEFICIT

Charles S. Fulco
Stephen R. Muza
Anne L. Friedlander
Paul B. Rock
Barry Braun
Carol J. Baker-Fulco
Allen Cymerman

THERMAL AND MOUNTAIN MEDICINE DIVISION

November 2006

U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

DISCLAIMERS

Approved for public release; distribution is unlimited.

The views, opinions and/or findings contained in this publication are those of the authors and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

For the protection of human subjects, the investigators adhered to policies of applicable Federal Law CFR 46.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRMC Regulation 70-25 on the use of volunteers in research.

Any citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement of approval of the products or services of these organizations

Approved for public release; distribution is unlimited.

DTIC AVAILABILITY NOTICE

Qualified requestors may obtain copies of this report from Commander, Defense Technical Information Center (DTIC) (formerly DDC), Cameron Station, Alexandria, Virginia 22314

DISPOSITION INSTRUCTIONS

Destroy this report when no longer needed.
Do not return to the originator.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

BACKGROUND

The current study was performed in the first year of a 3-year collaborative research project between the Palo Alto Veterans Health System (PAVA, Palo Alto, CA) and the U.S. Army Research Institute of Environmental Medicine (USARIEM, Natick, MA). The entire project, "Effect of Energy Deficit on Work Performance at 4,300 m Elevation," was funded by a 3-year grant awarded to PAVA and USARIEM by the Cooperative VA/DoD Medical Research Program in the area of physiological foundations of physical performance and combat readiness.

The overall purpose of the project in the first year was to evaluate the effects of a severe energy deficit (approximately –1500 Kcal•day^{-1} or 40% of weight stabilization need) at sea level and combined with 3 weeks of high altitude exposure (4,300 m) on physical and mental performance. Included were measures of whole-body and isolated muscle group exercise performances, body composition, acute mountain sickness, respiratory muscle performance, substrate metabolism, postural stability, and mood states. Presented in this report are the effects of severe energy deficit on endurance performance during 3 weeks of high altitude residence.

EXECUTIVE SUMMARY

Body weight (BW) and lean body mass (LBM) of sea-level (SL) residents are typically reduced by < 4% and < 2%, respectively, while endurance performance is greatly impaired initially but then improves during the first 3 weeks of altitude exposure. The purpose of this study was to determine if a greater reduction in LBM due to severe energy intake deficit will eliminate the performance improvement despite maintenance of a high carbohydrate (CHO) diet. Two groups of men (mean ± SE: 22 ± 1 yrs) were matched at SL on cycle peak oxygen uptake ($\dot{V}O_{2peak}$), cycle endurance performance (50% of $\dot{V}O_{2peak}$ for 50 min followed by 70% of $\dot{V}O_{2peak}$ to exhaustion), total energy intake, and percentage of energy from CHO (%CHO). At DEFINE ALT (ALT), the deficit group (DEF, n = 10) consumed 1340 kcal•day^{-1} (-40%) below BW maintenance requirements, and the adequately fed group (ADQ, n = 7) ingested enough energy to maintain BW. Both groups ingested similar %CHO (~64 to 71%) and > 347 g of CHO•day^{-1} at SL and ALT. Endurance performance was again assessed at ALT on Days 1 and 18 using the identical absolute power outputs that were used at SL for 50% (149 ± 4 watts) and 70% (218 ± 6 watts) $\dot{V}O_{2peak}$. From SL to Day 18 at ALT, BW was reduced for DEF (80.4 ± 12 to 74.3 ± 3 kg; -8 ± 2%; P<0.01) but not ADQ (74.4 ± 3 to 73.3 ± 3 kg; -1 ± 1%). Similarly, LBM (estimated from a circumference measure) was reduced for DEF (71.0 ± 10 to 66.4 ± 7 kg, -6 ± 1%; P<0.01) but not ADQ (66.3 ± 5 to 64.9 ± 5 kg; -2 ± 1%). On either day at ALT, there was no difference between groups in endurance time. For both groups, endurance performance at ALT was 6 ± 2% greater on Day 18 (57 ± 2 min) than on Day 1 (54 ± 1 min; P<0.012). It was concluded that during the first 3 weeks of ALT acclimatization, a 6% loss in LBM due to underfeeding did not adversely affect the improvement in endurance performance. The lack of effect on performance during severe energy deficit may have been due to the maintenance of muscle glycogen stores or a lower rate of muscle glycogen utilization for the same amount of work.

INTRODUCTION

Much of what is known of the physical performance changes associated with altitude exposure, *per se*, is based on information collected during research studies or sporting events from individuals who resided under controlled or reasonably comfortable conditions. For many such undertakings, individuals were offered a varied menu of numerous items where the quantities of food and fluid were adequate to maintain body weight (BW). Yet despite such provisions, weight losses of 2 to 3 kg (or 2% to 4% of BW for an 80 kg person) after 21 days of altitude residence at 4300 m, for example, are common (11).

Relatively small BW losses apparently do not cause further impairment in peak oxygen uptake ($\dot{V}O_{2peak}$) that is already reduced by ~30% during initial exposure to 4300 m without weight loss (6, 11). Moreover, there typically is an improvement in endurance exercise performance during residence at the same elevation (6) . For such reasons, a small BW loss has long been considered an expected and not unfavorable component of normal altitude acclimatization.

In contrast, some individuals (e.g., military personnel during field operations) typically lose 7 kg or 9% or more of BW in a similar period of time that results from caloric intakes that are 40% to 50% less than BW stabilization needs (1). Body weight losses of this magnitude at sea level (SL) have resulted in ~10% reduction in $\dot{V}O_{2peak}$ and comparative declines in endurance exercise performance (12). The implication is that a large BW loss with a proportionally large loss in lean body mass (LBM) at altitude may cause impairments in physical performance and alter physiological responses to exercise that are in addition to those associated with altitude exposure alone.

The primary objective of this investigation was to evaluate the effect of a severe deficit energy intake (~ 40% of weight stabilization need) on performance and the responses to exercise in individuals living at 4300 m altitude for 3 weeks. To minimize the potential confounding effect of low muscle glycogen stores on endurance performance, daily carbohydrate intake was maintained at >347 g or 64% of total caloric intake.

METHODS

SUBJECTS

Twenty men were recruited from advertisements and fliers placed in local newspapers and universities in and around the Palo Alto/San Jose, CA, area. As part of the recruiting inclusion/exclusion criteria, all had to be (i) nonsmokers, (ii) normal weight for height, (iii) 21 to 35 years old, (iv) require at least 2700 kcal•day^{-1} for maintenance of BW, (v) BW stable for previous 6 months, (vi) in good health with no chronic illnesses, (vii) born at an altitude less than 2000 m, (viii) residing at or near SL in the previous 3 years and not made visits to altitudes greater than 2000 m within the last 3 months, and (ix) participating in a regular exercise program. All signed a consent form approved by all institutions

involved in the research. For the protection of the subjects, investigators adhered to policies of applicable Federal Law CFR 46. They then had a physical examination that included a medical history assessment, resting 12-lead electrocardiogram, routine blood and urine analyses, and a nutrition assessment.

STUDY DESIGN

All subjects were studied at SL at the Clinical Studies Unit of the Palo Alto Veterans Health Center while being fed a controlled diet by dietitians for 12 days to attain energy and nitrogen balance, and BW stabilization. For each subject on their first day, basal energy expenditure (BEE) was estimated using the Harris-Benedict equation (8), and caloric need was calculated by multiplying the BEE by an activity factor of 1.7-2.0, based on the subject's reported daily activity level (3) obtained during the screening process. The subjects were then weighed nude at least every other day on a frequently calibrated scale (accurate to 10 g, Cardinal Scale Manufacturing Co, Model 758) to assure weight stability during the diet consumption period. Caloric adjustments were made as required. Dietitians in the Clinical Studies Unit have used this methodology to achieve BW stability successfully for over 20 years. During this SL baseline phase, physical performance tests were performed.

After the SL baseline phase, subjects were divided into two groups of 10, matched on SL total daily energy intake, daily percentage carbohydrate intake, cycle ergometer $\dot{V}O_{2peak}$, and cycle ergometer endurance performance. However, because of scheduling conflicts between study dates and the personal affairs of some subjects, three voluntarily withdrew from the project before being deployed to the USARIEM High Altitude Research Laboratory at the summit of Pikes Peak (4300 m). Seven remained in the energy adequate (ADQ) group, and ten remained in the energy deficient (DEF) group. Both groups subsequently resided at altitude for 21 days. While at altitude, the subjects of the ADQ group attempted to consume enough kcal•day^{-1} to maintain BW, while the subjects of the DEF group were provided a diet deficient in kcal•day^{-1} by ~ 40% of the calories (or approximately –1500 kcal•day^{-1}) required for BW maintenance.

DIET

The diet consisted of real whole foods provided to each subject in individualized amounts. Protein content of the diet was held constant (1.2 g of protein•kg BW^{-1}•day^{-1}), while energy intake was adjusted by adding or subtracting fat- and carbohydrate-containing foods. Emphasis was placed on maintaining a diet high in carbohydrate. The BW maintenance diet therefore consisted of approximately 12% protein, 20% fat, and 68% carbohydrate. During the 21-day phase at altitude, the subjects in the DEF group ate approximately 60% of their BW stabilization diet, while the subjects in the ADQ group ate their BW stabilization diet. Energy deficit was created by decreasing the intake of fat and carbohydrate foods, but keeping the carbohydrate intake at least 3 gm•kg^{-1}•day^{-1} to minimize the effect of low carbohydrate intake on glycogen stores. In addition, during the 21-day phase at altitude, the subjects in the DEF and ADQ groups ate an extra 200

kcal•day^{-1} to account for the altitude-induced increase in metabolic rate (2). To insure adequate intake of nutrients, a multi-vitamin and mineral supplement was provided daily.

TRAVEL TO ALTITUDE

All ADQ and DEF subjects were flown in groups of two each day to Colorado Springs, CO, (1,800 m) and spent one night in an apartment while on supplemental oxygen supplied by an oxygen concentrator to maintain SL oxygen saturation levels. In the morning, the pair was driven to 4300 m elevation at the summit of Pikes Peak in Colorado, while still breathing oxygen via a mask. After arriving on the summit, the subjects removed their masks. To better maintain morale and diet compliance at altitude, data collection on all subjects in the DEF group was completed before data collection on subjects in the ADQ group was begun.

PROGRAMMED EXERCISE

Activity level was monitored through 24-hour activity diaries at SL. A program of exercise, including cycle ergometry, treadmill walking, and weight lifting, was devised for each subject to be undertaken at altitude. The exercise program at altitude served to prevent detraining, as well as to balance energy expenditure under the two environmental conditions.

BODY COMPOSITION

Body weight was measured each morning throughout the study using the identical scale as at SL (Cardinal Scale Manufacturing Co, Model 758). A waist circumference measurement was obtained during the SL baseline phase and on Days 3 and 21 during the altitude phase. The BW and circumference measurements were used in an equation (13) to estimate LBM, fat mass, and percentage fat.

PHYSICAL PERFORMANCE

Peak Oxygen Uptake

An incremental progressive exercise bout to volitional exhaustion on an electrically braked bicycle ergometer (Excaliber, Lode BV, Groningen, The Netherlands) was used to assess $\dot{V}O_{2peak}$. Following resting measurements, subjects began pedaling at 70 rpm at 50 watts for a 5-min warm-up. Power output was then increased stepwise every 2 min until O_2 uptake failed to increase or the subject stopped the test. A three-lead electrocardiogram was used to monitor heart rate, and expired air was analyzed for respiratory volumes and O_2 uptake using a metabolic cart (Vmax 229 Sensormedics Inc., Yorba Linda, CA). Peak O_2 uptake for all subjects was determined during the SL baseline phase and at altitude on Days 2 and 20.

Endurance Performance

During the SL baseline phase and on Days 1 and 18 at altitude, the subjects performed a two-stage endurance exercise performance task. At SL, the subjects cycled on an electrically braked ergometer (Excaliber, Lode BV, Groningen, The Netherlands) for 50 min at 50% of SL $\dot{V}O_{2peak}$ and then to exhaustion at 70% $\dot{V}O_{2peak}$. During the altitude phase, the identical power outputs were used as at SL. In other words, the subjects cycled for 50 min at 149 ± 4 watts and to exhaustion at 218 ± 6 watts in both environments.

During the first 50 min of all endurance exercise performance tasks, heart rate (Polar Electro, Woodbury, NY), arterial oxygen saturation via finger pulse oximetry (Model N-200, Nellcor, Pleasanton, CA), and minute ventilation ($\dot{V}_E$) and respiratory quotient (RQ) (Vmax 229 Sensormedics Inc., Yorba Linda, CA) were collected.

STATISTICS

A two-factor (days X group) analysis of variance with repeated measures on one factor (days) were utilized for nearly all measures. Post-hoc analyses (Newman-Keuls) were performed where appropriate. Statistical significance was accepted when $P < 0.05$.

RESULTS

The age, BW, heights, percentage body fat, and body mass index of the subjects on Day 5 of their respective 7-day BW maintenance baseline phase at SL are presented in Table 1. There were no differences in age, height, percentage body fat, and body mass index between groups. Body weight of the subjects in the ADQ group was less than the BW of the subjects in the DEF group.

Table 1. Baseline Physical Characteristics of Subjects.

Group:	Age (yrs)	Weight (kg)	Height (cm)	Body Fat (%)	BMI ($BW/(Ht)^2$)
Deficit (n = 10)	22.6 ± 4	80.4 ± 12	178.9 ± 6	11.5 ± 4	25.0 ± 2
Adequate (n = 7)	21.1 ± 3	74.4 ± 7[a]	176.1 ± 5	10.7 ± 4	24.0 ± 2

Values are means ± SD; BMI = Body Mass Index (kg/m^2); [a]$P<0.01$ from Deficit group.

In Table 2 are the SL and altitude dietary results for the deficit and adequate groups. At SL, mean daily total Kcal and the macronutrient percentages were quite similar between groups. At altitude, the adequate group maintained mean daily total Kcal and macronutrient percentages similar to their values at SL. However, the mean total energy intake of the deficit group was, by experimental design, 41% less at altitude than at SL. Likewise, the absolute amount of CHO and fat Kcals were less at altitude than at SL. The

percentage of macronutrients to total Kcal ingested were similar between groups and environments.

Table 2. Energy Intake and Composition at Sea Level and Altitude.

Group:	Kcal (Total)	CHO (g, %Total Kcal)	Protein (g, %Total Kcal)	Fat (g, %Total Kcal)
Deficit				
SL Baseline	3530	589g, 67%	100g, 11%	86g, 22%
Altitude	2188	348g, 64%	87g, 16%	50g, 21%
	(-41%)[a]			
Adequate				
SL Baseline	3340	574g, 69%	90g, 11%	76g, 20%
Altitude	3618	642g, 71%	88g, 10%	78g, 19%
	(+3%)[a]			

Values are means. [a]Percentage change from SL baseline

The reduced food intake for the deficit group caused a large reduction in BW (Table 3 and Figure 1) and LBM (Table 4 and Figure 2) over the 21 days at altitude. Body weight and LBM for the deficit group were reduced by 8 ± 2% and 6 ± 1%, respectively, from SL to Day 21 at altitude. In contrast, the BW and LBM were not changed at altitude compared to SL for the adequate group.

Table 3. Body Weight Changes.

Group:	SL Baseline	Day 3	Day 21
Deficit	80.4 ± 12	77.8 ± 10	73.8 ± 9*,#
Adequate	74.4 ± 7[a]	74.1 ± 7[a]	73.4 ± 7

Units are kgs, means ± SD; [a]P < 0.01 from Deficit group; [#]P < 0.01 from Day 3.

Figure 1. Percentage decline in body weight

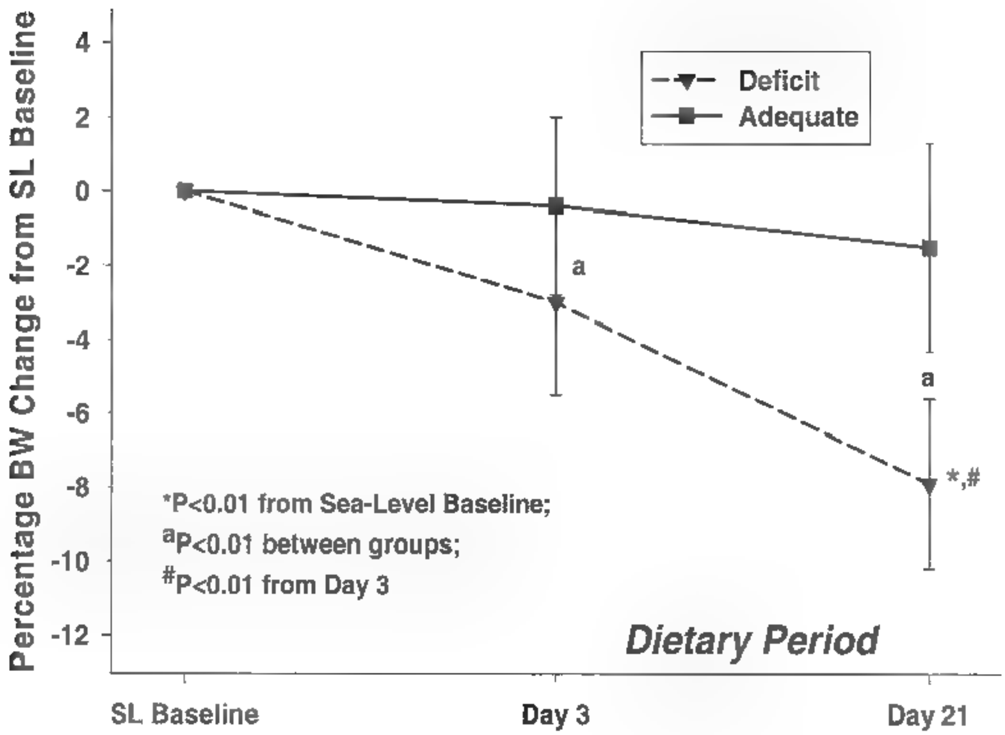
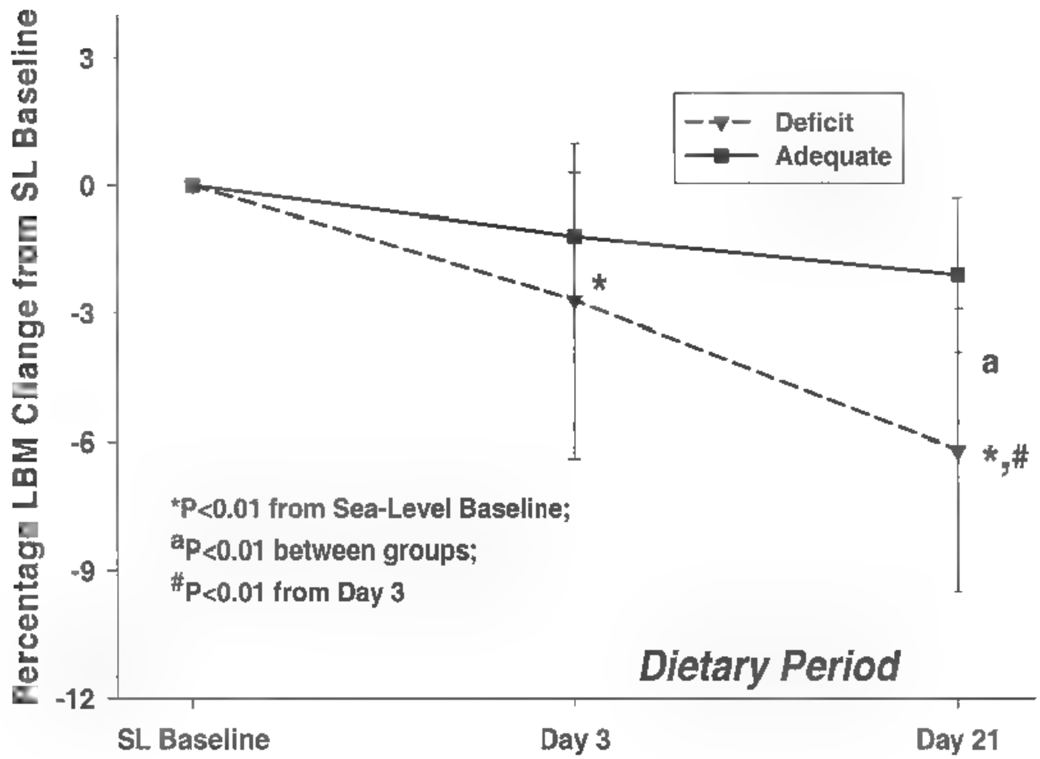


Table 4. Lean Body Mass Changes.

Group:	SL Baseline	Day 3	Day 21
Deficit	71.0 ± 10	68.8 ± 7*	66.4 ± 7*,#, a
Adequate	66.3 ± 5[a]	65.5 ± 5	64.9 ± 5

Units are kgs, means ± SD; *P < 0.01 from SL Baseline; #P < 0.01 from Day 3; [a]P < 0.01 from Deficit group.

Figure 2. Percentage decline in lean body mass



The large decline in BW and LBM apparently had no effect on either $\dot{V}O_{2peak}$ (Figure 3) or endurance performance (Figure 4). For both performance measures for both groups, there was a large reduction from SL to altitude (P<0.01). However, neither $\dot{V}O_{2peak}$ or endurance performance differed between groups after the large weight loss at altitude. Moreover, endurance performance for both groups increased by 6% from Days 1 to 18 at altitude.

Figure 3. Percentage decline in peak oxygen uptake

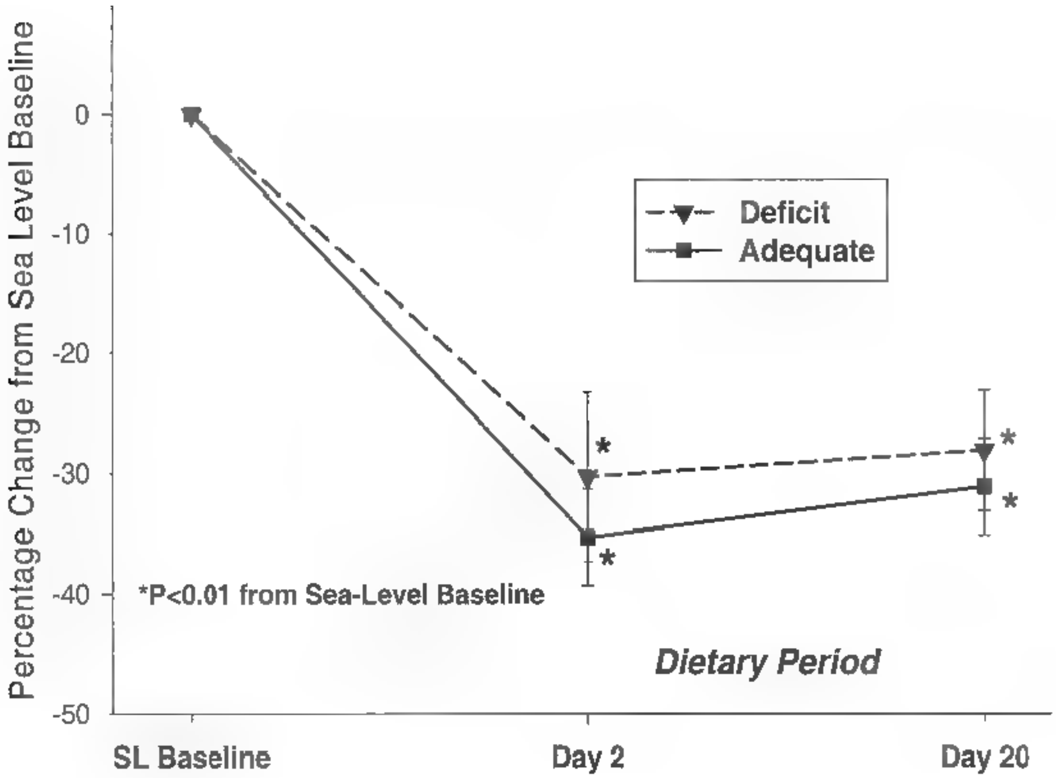
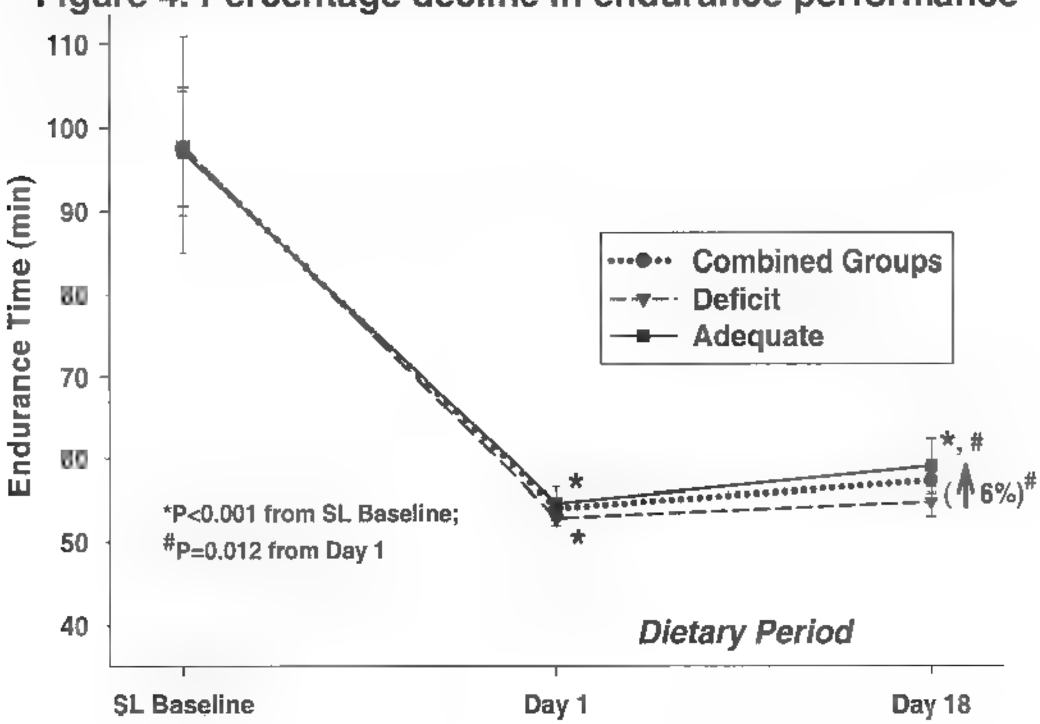


Figure 4. Percentage decline in endurance performance



The SL to altitude changes in heart rate, arterial oxygen saturation, and ventilation during exercise at the same absolute power output used at SL and altitude (149 ± 4 watts) are presented in Figures 5, 6, and 7, respectively. All three measures were changed from SL to Day 1 at altitude due to hypoxia, and further changed from Days 1 to 18 at altitude as a result of altitude acclimatization. For each of the measures, there was no difference between groups either at SL or altitude. In contrast, the respiratory quotient (Figure 8) during exercise for the deficit group was significantly lower than that of the adequate group after weight loss on Day 18 at altitude (1.00 ± 0.01 vs. 0.94 ± 0.02, P<0.013).

Figure 5. Exercise heart rate at a fixed power output

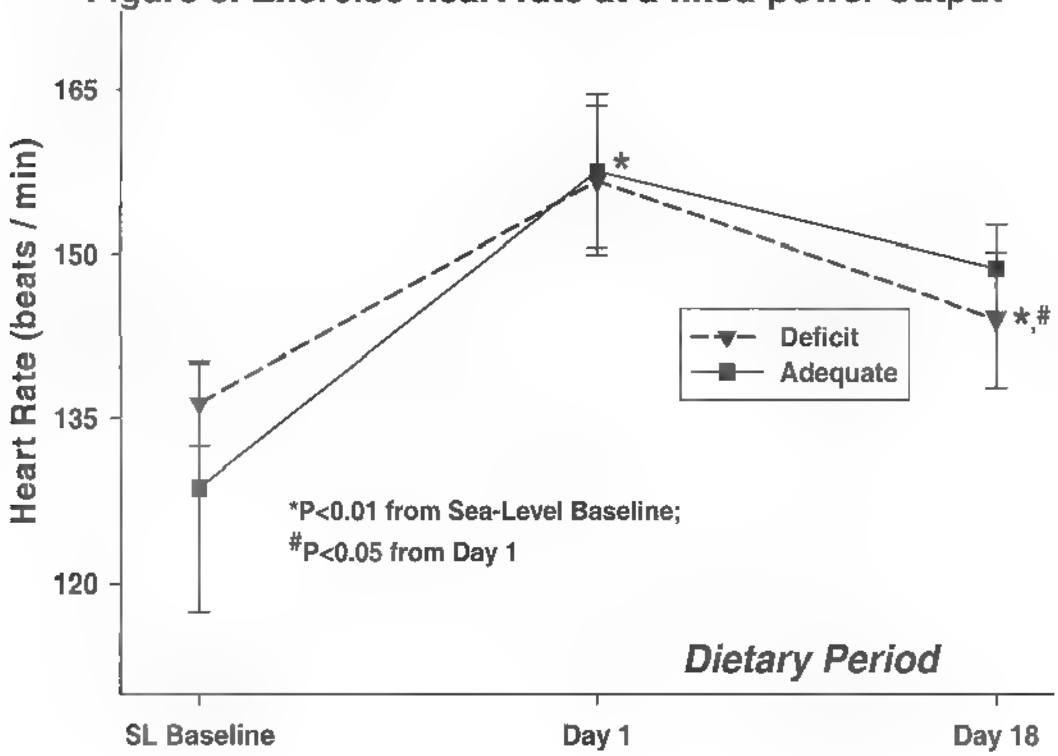


Figure 6. Oxygen saturation at a fixed power output

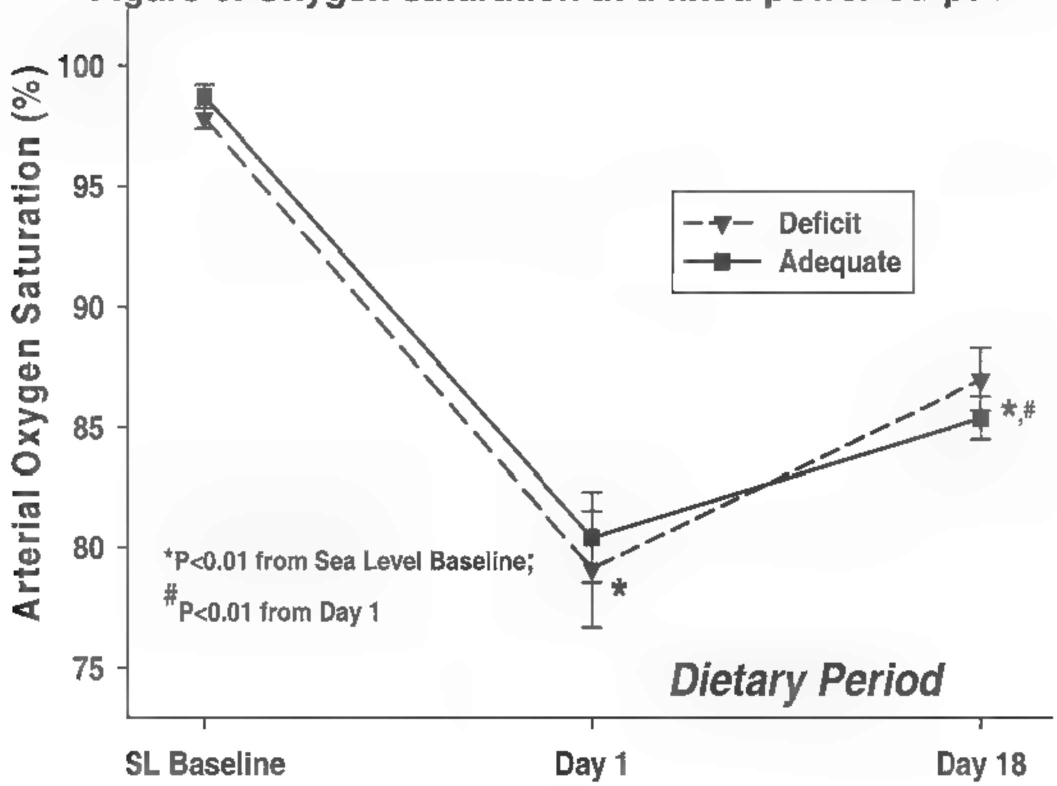


Figure 7. Minute ventilation at a fixed power output

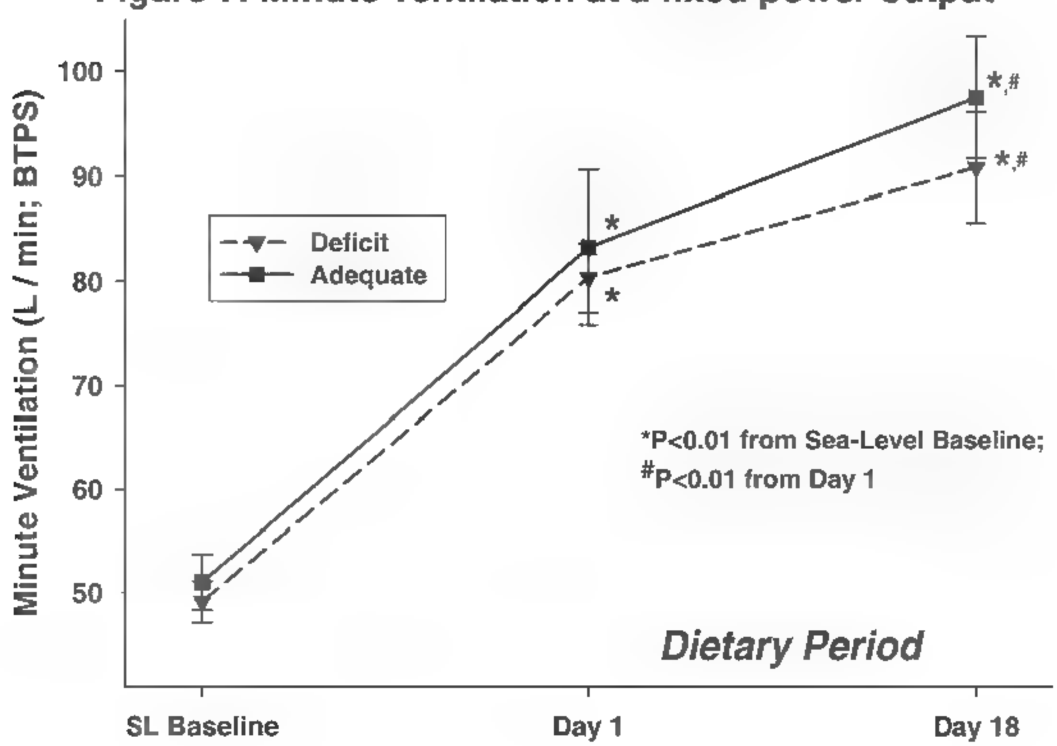
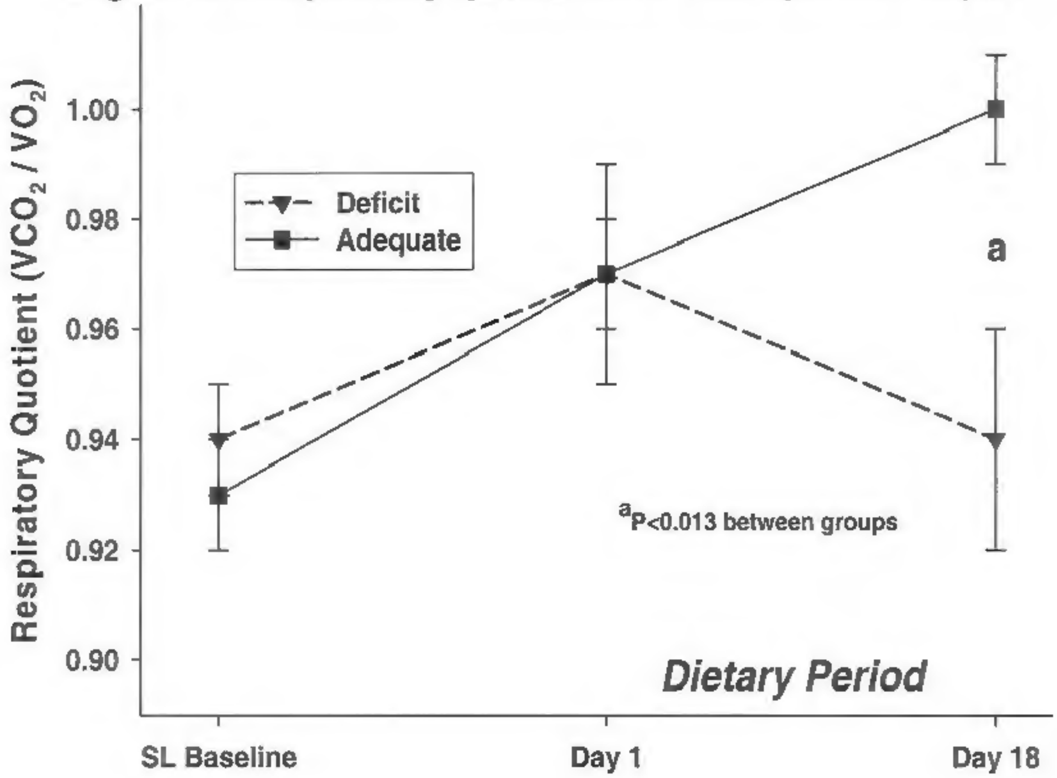


Figure 8. Respiratory quotient at a fixed power output



DISCUSSION

It is well known that with initial high-altitude exposure, $\dot{V}O_{2peak}$ is reduced significantly (6). Moreover, because of the reduction in $\dot{V}O_{2peak}$, there is also an proportional decline in endurance exercise performance that requires the same absolute power output at altitude as at SL (7). After 3 weeks of altitude acclimatization, with minimal weight loss, endurance performance typically *improves* due to a variety of respiratory, circulatory, and local muscle physiological adaptations despite no improvement in $\dot{V}O_{2peak}$ (4, 9, 10).

The goal of the current investigation was to determine whether more substantial BW and LBM losses resulting from severe energy restriction during the initial 3 weeks of high-altitude residence would further decrease $\dot{V}O_{2peak}$ and endurance exercise performance, and alter physiological responses to exercise. To that end, $\dot{V}O_{2peak}$, endurance performance, and responses to exercise were compared between a deficit energy group (-1340 kcal•day^{-1}) and an adequately fed, body-weight-maintained group (i.e., no daily caloric deficit) during residence at 4300 m altitude.

The subjects in the deficit group lost an average of 8% BW and 6% LBM. Yet $\dot{V}O_{2peak}$ and endurance exercise performance did not differ between groups, and for both groups, endurance performance improved by 6% from Days 1 to 18 at altitude. Moreover, steady-state exercise heart rate, minute ventilation, and SaO_2 did not differ between groups on any test day. Overall, these data indicate that a large loss in LBM did not exacerbate the altitude-induced reductions in $\dot{V}O_{2peak}$ or endurance exercise performance, and did not alter the physiological responses to exercise that are commonly reported during the first 3 weeks of high altitude exposure (11) . These results and conclusions are consistent with and extend our previous findings of no changes in small muscle group exercise or a whole-body "lift and carry" task during similar BW loss during 3 weeks of residence at 4300 m (5).

One reason for a lack of decrement in exercise performance in the present study may relate to the maintenance of a relatively high CHO diet that likely sustained muscle glycogen stores despite a large daily energy restriction. Alternatively, a finding of a lower RQ during submaximal exercise at the same work rate after weight loss at altitude is consistent with a lessened reliance on CHO oxidation such that the rate of muscle glycogen utilization was reduced. Whether either or both explanations is tenable is beyond the scope of this investigation.

CONCLUSION

A substantial caloric deficit of 1340 kcal•day^{-1} for 21 days at 4300 m altitude caused an 8% BW loss and a 6% LBM loss, but did not adversely affect maximal or submaximal endurance exercise performance.

REFERENCES

1. **Baker-Fulco C.J.** Overview of dietary intakes during military exercises. In: *Not Eating Enough*, edited by B.M. Marriot. Washington, D.C.: National Academy Press, 1995, p. 121-149.

2. **Butterfield G.E.** Maintenance of body weight at altitude: in search of 500 Kcal/day. In: *Nutritional Needs in Cold and in High-Altitude Environments*, edited by B.M. Marriot and S.J. Carlson. Washington,D.C.: National Academy Press, 1996, p. 357-378.

3. **Durnin J.V.G.A. and R. Passmore**. *Energy, Work, and Leisure.* London: Heinemann Educational Books, 1967.

4. Fulco C.S., A. Cymerman, S.R. Muza, P.B. Rock, K.B. Pandolf and S.F. Lewis. Adductor pollicis muscle fatigue during acute and chronic altitude exposure and return to sea level. *J Appl Physiol* 77: 179-183, 1994.

5. Fulco C.S., A.L. Friedlander, S.R. Muza, P.B. Rock, S. Robinson, E. Lammi, C.J. Baker-Fulco, S.F. Lewis and A. Cymerman. Energy intake deficit and physical performance at altitude. *Aviat Space Environ Med* 73: 758-765, 2002.

6. Fulco C.S., P.B. Rock and A. Cymerman. Maximal and submaximal exercise performance at altitude. *Aviat Space Environ Med* 69: 793-801, 1998.

7. Gleser M.A. and J.A. Vogel. Effects of acute alterations of VO2max on endurance capacity of men. *J Appl Physiol* 34: 443-447, 1973.

8. **Harris J.A. and F.G. Benedict**. *A Biometric Study of Basal Metabolism in Man.* Washington, D.C.: Carnegie Institution, 1919.

9. Horstman D., R. Weiskopf and R.E. Jackson. Work capacity during 3-wk sojourn at 4,300m: effects of relative polycythemia. *J Appl Physiol* 49: 311-318, 1980.

10. Maher J.T., L.G. Jones and L.H. Hartley. Effects of high-altitude exposure on submaximal endurance capacity of men. *J Appl Physiol* 37: 895-898, 1974.

11. **Mazzeo R.S. and C.S. Fulco**. Physiological systems and their responses with exposure to hypoxia. In: *ACSM's Advanced Exercise Physiology*, edited by Charles Tipton. Philadelphia, PA: Lippincott Williams & Wilkins, 2006, p. 564-580.

12. Taylor H.L., E.R. Buskirk, J. Brozek, J.T. Anderson and F. Grande. Performance capacity and effects of caloric restriction with hard physical work on young men. *J Appl Physiol* 10: 421-429, 1957.

13. Wright H.F. and J.H. Wilmore. Estimation of relative body fat and lean body weight in a United States Marine Corps population. *Aerospace Med* 45: 301-306, 1974.